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High Speed Jet Noise Prediction Using Large Eddy Simulation

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Final Report on Grant NAG 2-1373

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Summary:

Current methods for predicting the noise of high speed jets are largely empirical. These empirical methods are based on the jet noise data gathered by varying primarily the jet flow speed, and jet temperature for a fixed nozzle geometry. Efforts have been made to correlate the noise data of co-annular (multi-stream) jets and for the changes associated with the forward flight within these empirical correlations. But ultimately these empirical methods fail to provide suitable guidance in the selection of new, low-noise nozzle designs. This motivates the development of a new class of prediction methods which are based on computational simulations, in an attempt to remove the empiricism of the present day noise predictions.

Successful noise prediction from a high-speed jet is not possible without first achieving an accurate flow prediction. Fortunately, jet flows are dominated by inviscid instabilities and hence their large-scale features (which contain most of the fluctuating energy) are largely independent of the Reynolds number. This makes the approach of large-eddy simulation (LES) attractive for a) studying the mixing properties of high-speed jets and b) for predicting the noise radiated by the turbulent mixing process occurring in the jet. Several technical challenges must be overcome in applying LES to the studies of jet noise: 1) The method must resolve the dominant energy-containing scales of jet turbulence (which is a major technical challenge in the early region of the jet where the turbulence scales are very small); 2) The near acoustic field need to be accurately captured in the simulations (this requires non-dissipative schemes with good control over the dispersive errors); 3) The boundary conditions need to be sufficiently accurate, and robust to the numerical errors and at the same time provide the correct physical behavior (silent passage of disturbances at out-flow, proper behavior at the jet centerline, smooth entrainment at radial boundary and anechoic for out-going acoustic disturbances); 4) The mechanisms by which the jet flow is modified for reducing its noise be represented in the calculation.

Specifics of the technical work conducted under the sponsorship of the NASA grant are described in the attached appendices. These include developments in the numerical algorithms to address the issues outlined above. A specific development which is of broader interest than the jet noise simulations, concerns the numerical treatment of the flow equations near the co-ordinate singularity (the jet centerline in present application). A new method was developed for this which provides very good accuracy and overcomes many difficulties faced in previous approaches. This method is described in appendix A. The progress made in conducting the LES of high-speed jet flows and its noise are described in appendix B. The work presented uses the new treatment of the co-ordinate singularity. Finally, in appendix C an approximate analysis of a new jet noise reduction scheme (involving injection of small-sized water drops) is presented. Its goal is to evaluate the potential offered by this approach towards altering the jet flow field and hence its noise.